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The ALICE electromagnetic calorimeter high level triggers

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Abstract. The ALICE (A Large Ion Collider Experiment) detector yields a huge sample of data from different sub-detectors. On-line data processing is applied to select and reduce the volume of the stored data. ALICE applies a multi-level hardware trigger scheme where fast detectors are used to feed a three-level (L0, L1, and L2) deep chain. The High-Level Trigger (HLT) is a fourth filtering stage sitting logically between the L2 trigger and the data acquisition event building. The EMCal detector comprises a large area electromagnetic calorimeter that extends the momentum measurement of photons and neutral mesons up to $p_T = 250$ GeV/c, which improves the ALICE capability to perform jet reconstruction with measurement of the neutral energy component of jets. An online reconstruction and trigger chain has been developed within the HLT framework to sharpen the EMCal hardware triggers, by combining the central barrel tracking information with the shower reconstruction (clusters) in the calorimeter. In the present report the status and the functionality of the software components developed for the EMCal HLT online reconstruction and trigger chain will be discussed, as well as preliminary results from their commissioning performed during the 2011 LHC running period.

1. Introduction

The ALICE experimental setup is read out at an overall data rate of up to 25 GByte/s. Thus on-line data processing must be applied in order to reduce the data volume. ALICE applies a multi-level hardware scheme where fast detectors are used to feed the Level-0/Level-1 (L0/L1) hardware trigger sequence, followed by a Level-2 (L2) trigger accept decision in the Central Trigger Processor available to provide past/future protection against pileup events. At the end of this chain, a more refined filtering stage is introduced: the High-Level Trigger (HLT), which is able to reduce the volume of the data stream to permanent storage by one order of magnitude. The HLT layer is designed to perform complex event selection functions via fast reconstruction algorithms in order to provide trigger decisions, select Regions-of-Interest, and compress the data. In addition to event selection and triggering tasks, the HLT produces online detector performance monitoring information and is able to perform on-line calibrations. The HLT on-line software components run within the publisher-subscriber data transport framework. In this context, EMCal specific processing components have been developed to perform reconstruction, monitoring, and triggering.

2. Overview of the EMCal hardware triggers

After a successful L0 and consecutive L1 and L2 accept trigger sequence, the HLT farm receives a copy of the raw data from each subsystem front-end and trigger electronics. Specifically, the EMCal[1] Front End Electronics (FEE) provides to the HLT chain a full copy of the raw data. In addition, hardware trigger primitives (such as the list of the calorimeter cell clusters satisfying the trigger condition) produced by the EMCal Summary Trigger Unit processor (STU) are recorded along with the raw data and are also provided to the HLT.

In *pp* collisions, the EMCal provides trigger input at L0 using a low threshold (2 GeV) to trigger on events with EMCal activity (electrons and photons) without bias from other trigger detectors. The L0 trigger for showers is provided by the fast analog 2×2 tower sums, also know as FastORs, and passed to a nearby Trigger Region Unit (TRU) where they are digitized. The digitized 2×2 signals are then summed in the FPGA of the TRU in overlapping (4×4) tower regions and then compared to a programable threshold to generate the L0 single shower trigger.

A single cluster trigger can be effectively generated by the leading particle of a jet (usually from a hard π^0). On the other hand, this trigger is significantly biased as a jet trigger since the leading particle does not carry the full jet energy. In addition, the bias is exacerbated in heavy ion collisions, when the leading particle is emitted deep inside the fireball and may lose energy and correlation with the other particles of the jet by traversing a large fraction of the QCD medium (an effect known as jet quenching[2]). Since a single EMCal trigger unit (TRU) sees only a fraction of the entire calorimeter acceptance, it is not suitable to generate a full jet trigger. To overcome this limitation, the digitized FastORs signals from all TRUs are passed to the STU FPGA which performs the integration over a programmable size window (denoted as jet patch) scanning over the entire EMCal acceptance. This L1 jet trigger provides a less biased trigger on high E_t jets [3, 4] by integrating the electromagnetic energy over a large phase space area to trigger on a significant fraction of the total jet energy,

The jet trigger decision is driven by a multiplicity-dependent threshold. For heavy ion collisions, a fixed jet energy threshold (with a value set to discriminate jets from the underlying energy in a jet patch region tuned for central events) would have an unacceptably high threshold for jet signals from peripheral events. The solution implemented provides the collision multiplicity information signal from a forward ALICE detector (V0) to the EMCal jet trigger unit (STU), to enable a centrality-dependent trigger threshold (recomputed on an event-by-event basis) to maintain an approximately uniform jet trigger efficiency across event centralities.

3. The EMCal HLT online chain

The EMCal L0 or L1 hardware trigger decisions provide the input for a dedicated on-line event processing chain running on the HLT cluster, where further refinement based on criteria using the full event reconstruction information is performed. In fact, the detector optical link transports the raw data to the Read-Out Receiver Card (RORC) in the local data collector of the data acquisition system, which sends a complete copy of the readout to a set of specialized nodes in the HLT cluster (FEP or Front End Processors). Each FEP node is equipped with RORC cards in analogy to the collector nodes used by the data acquisition. The FEP nodes are physically linked to the detector hardware and reflect the geometrical partitioning of each ALICE subsystem. Specifically, the EMCAL is composed of 10 full-size super-modules of 1152 channels and 2 reduced-size super-modules of 384 channels, for a total of 12 288 channels, covering an azimuth $\Delta\phi = 110\,\mathrm{deg}$ and a pseudo-rapidity $-0.7 \leq \Delta\eta \leq 0.7$. The 10 full-size super-modules are read out using 2 Read-Out Control Units (RCUs) for a total of 20 optical links running into the HLT FEPs. The reduced-size super-modules were installed prior to the 2012 LHC run and are not discussed in the present report. In addition to the 20 links from the super-module readout, the HLT receives also a copy of the L0/L1 trigger data stream via an additional optical link from the EMCal jet trigger unit (STU) data collector. The different stages of data

processing are then performed by the software analysis chain executed on the HLT cluster: a set of general purpose nodes (Computing Nodes or CNs) perform the higher level operations on the data streams which have been already pre-processed on the FEPs at the lower level. The EMCal software components form a specialized sub-chain executed at run time together with all other ALICE sub-systems participating in the HLT event reconstruction.

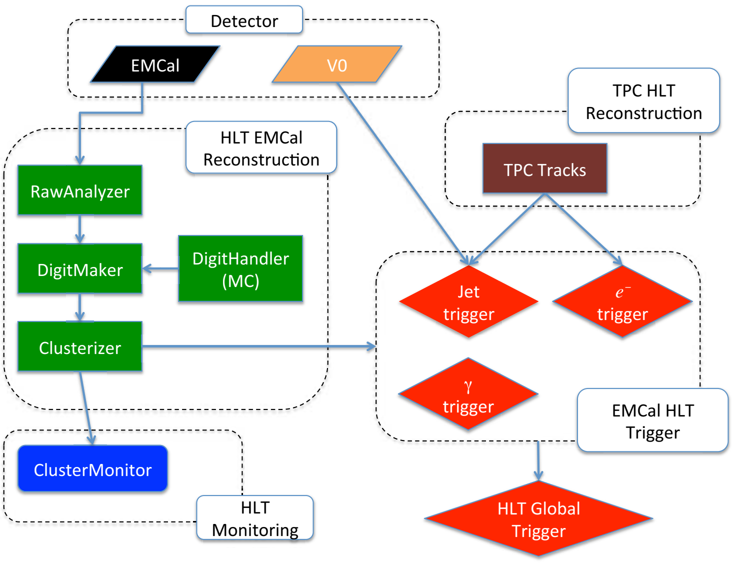

Figure 1. Functional diagram of the EMCal online reconstruction components (signal processing, data structure makers, and clusterizers) shown in green. The EMCal chain is fed by the detector raw data. Trigger components are shown in red. EMCal-specific triggers operate on the calorimeter clusters and perform TPC track-matching when needed (electron and jet triggers). Monitoring components are shown in blue and live in a separate monitoring chain. The EMCal triggers are evaluated within the Global Trigger which is aware of the full HLT trigger logic of the other ALICE detectors.

The functional units of the EMCal HLT online chain are presented in Figure 1 where the online reconstruction, monitoring, and trigger components are shown together with their relevant data paths. The lower-level EMCal online component (*RawAnalyzer*) is fed by the detector front end electronics and performs signal amplitude and timing information extraction. Intermediate components (*DigitMaker*) use this information to build the digitized data structures needed for the clusterizer components to operate on the cell signals. Alternatively, the digitized signals can be generated via monte carlo simulations (*DigitHandler*).

At the top of the EMCal reconstruction chain, the digits are summed by the *Clusterizer* component to produce the cluster data structures. The calorimeter clusters are then used to generate the different kinds of EMCal HLT trigger information: a single shower trigger (γ) with no track matching, an electron trigger using the matching with a corresponding TPC track, and a jet trigger also using the TPC tracks information and the V0 multiplicity dependent threshold.

The trigger logic generated by the EMCal chain is evaluated (together with the outputs of the HLT trigger components coming from other ALICE detectors) within the HLT Global Trigger which produces the final high level decision based on the reconstructed event. The ALICE data acquisition system will then discard, accept or tag the event according to the HLT decision.

For performance and stability reasons, the full on-line HLT chain contains only analysis and trigger components. On the other hand, monitoring components typically make heavy use of histogramming packages and ESD objects, hence they are kept in a separate chain. The isolation of the monitoring from the reconstruction chain gives additional robustness since a crash in a monitoring component will not affect the reconstruction chain and the data taking.

4. Reconstruction components

As shown in Figure 1 the EMCal HLT analysis chain provides all the necessary components to allow the formation of a trigger decision based on full event reconstruction. The following

subsections are devoted to a detailed discussion of each processing stage, starting from the most basic, i.e. signal extraction, to the highest stage: the HLT trigger decision.

4.1. RawAnalyzer

The *RawAnalyzer* component extracts energy and timing information for each calorimeter cell. Extraction methods implemented in the offline code (AliRoot) typically use least squares fitting algorithms, and cannot be used in online processing for performance reasons. Conversely, the HLT signal extraction is done without need of fitting using two possible extraction methods. The first method, referred to as *kCrude*, simply produces an amplitude using the difference between the maximum and the minimum values of the digitized time samples and associates the time bin of the maximum as the signal arrival time. The *kCrude* method was used during the 2011 data taking: it has the advantage of being extremely fast and fully robust since no complex algorithms are used. On the other hand, it produces a less accurate result than the processing of the full signal shape. An alternative method (*kPeakFinder*[5]) evaluates the amplitude and peak position as a weighted sum of the digitized samples. This approach is not as fast as *kCrude* but is a few hundred times faster than least squares fitting.

4.2. DigitMaker

The *DigitMaker* component essentially transforms the raw cell signal amplitudes produced by the *RawAnalyzer* into digit structures by processing the cell coordinates and by the application of dead channel maps and the appropriate gain factors (low and high-gain).

4.3. Clusterizer

The *Clusterizer* component merges individual signals (digits) of adjacent cells into structures called clusters. At transverse momenta $p_T > 1$ GeV/c most of the clusters are associated to electromagnetic showers in EMCal from π^0 and η mesons decays. Other sources of electromagnetic showers are direct photons and electrons from semi-leptonic decays of c and b hadrons. Since the typical cluster size in the EMCal can vary according to the detector occupancy due to shower overlap effects, which are much different for *pp* and heavy-ion collisions, clustering algorithms with and without a cutoff on the shower size are available (both in offline and in the HLT) to optimize the cluster reconstruction for the different cases. Events originating from *pp* collisions tends to generate smaller, spherical and well-separated clusters in the EMCal, at least up to 10 GeV/c. At higher transverse momenta, overlapping of the showers requires a shape analysis to extract the single shower energy. Above 30 GeV/c the reconstruction can be performed only with more sophisticated algorithms such as isolation cuts to identify direct photons.

The identification of an isolated single electromagnetic cluster in the EMCal can be performed using different strategies: summing up all the neighboring cells around a seed-cell over threshold until no more cells are found or adding up cells around the seed until the number of clustered cells reaches the predefined cutoff value.

The first approach is more suitable for an accurate reconstruction. A further improvement to this clustering algorithm would be the ability to unfold overlapping clusters as generated from the photonic decay of high-energy neutral mesons, however this procedure usually requires computing intensive fitting algorithms.

Such performance penalty must be avoided in the online reconstruction so the cutoff technique is preferred. In the EMCal HLT reconstruction a cutoff of 9 cells is used (according to the geometrical granularity of the single cell size), so the clusterization is performed into a square of 3×3 cells. The cutoff and non-cutoff algorithms are referred to as $N \times N$ and $V1$, respectively.

In *pp* collisions the response of the two methods is very similar since the majority of clusters are well separated, while in *PbPb* collisions, especially in central events, the high particle

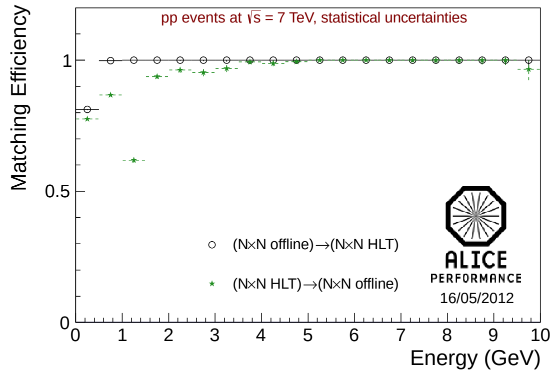

Figure 2. Reconstruction efficiency for the $N \times N$ algorithm (cutoff) in offline and HLT. The notation $(A) \rightarrow (B)$ indicates the fraction of clusters found using method A that are also found using method B (data from run 154787, period LHC11c).

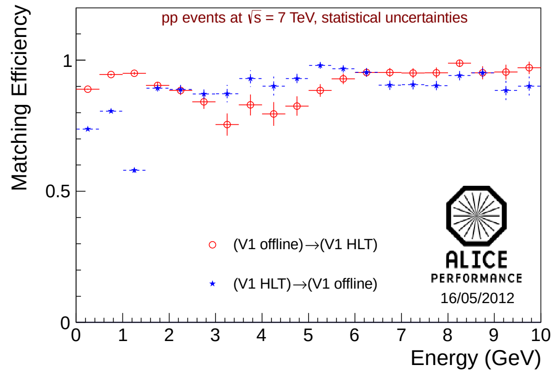

Figure 3. Reconstruction efficiency for the $V1$ algorithms (no cutoff) in offline and HLT. The notation $(A) \rightarrow (B)$ indicates the fraction of clusters found using method A that are also found using method B (data from run 154787, period LHC11c).

multiplicity requires the use of the cutoff (or unfolding in offline) to disentangle the cluster signals from the the underlying event to avoid the generation of artificially large clusters.

The quality of the EMCal online clusterizer algorithms implemented in the HLT chain were checked against offline, as shown in Figures 2 and 3 where it can be seen that the performance is in a reasonable agreement in all cases. The low point at 1.25 GeV is due to bad towers, which are assigned an energy of 1 GeV. Bad clusters are removed in later stages of the analysis, but that is not yet reflected in Figures 2 and 3. This effect leads to an excess of clusters that are found by the HLT clusterizer, but not by the offline clusterizer.

Since the EMCal HLT reconstruction is mainly targeted for triggering, a small penalty in the accuracy of the energy reconstruction of the clusters is accepted as a trade off in favor of faster performance, and for this reason the cutoff clustering method was used, especially in *PbPb* collisions.

5. Trigger components

The online HLT chain is capable of producing trigger decisions based on full event reconstruction. In terms of EMCal event rejection the following relevant trigger observables have been implemented:

- neutral cluster trigger
- electron and jet trigger

5.1. Cluster trigger

The single shower triggering mode is primarily targeted to trigger on photons and neutral mesons. In all collision systems, the high level trigger post-filtering can improve the hardware L0 and L1 trigger response by using the current bad channels map information and calibration factors (which could be recomputed directly in the HLT).

5.2. *Electron trigger*

For this trigger the cluster information reconstructed online by the EMCal HLT analysis chain is combined with the central barrel tracking information to produce complex event selection as a single electron trigger (matching of one extrapolated track with an EMCal cluster. Performance and accuracy studies of the track matching component developed for this purpose have been done using simulated and real data taken during the 2011 LHC running period. Results are shown in Figures 4 and 5 where the cluster - track residuals in azimuth and pseudo-rapidity units are to be compared with a calorimeter cell size of 0.014×0.014.

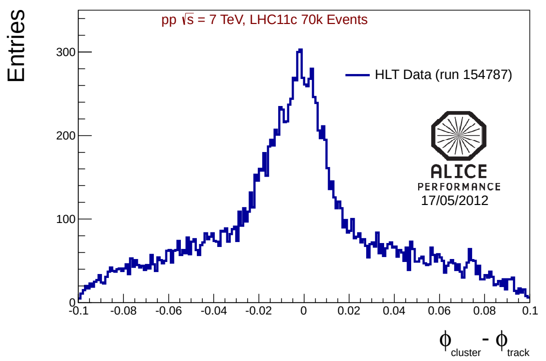

Figure 4. Distribution of the residuals in azimuth ($\Delta\phi$) for the EMCal cluster and central barrel tracks obtained using the HLT online chain for run 154787 (LHC11c), 70 k events reconstructed.

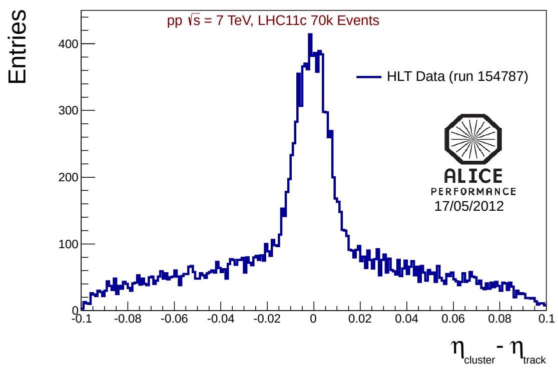

Figure 5. Distribution of the residuals in pseudo-rapidity ($\Delta\eta$) for the EMCal cluster and central barrel tracks obtained using the HLT online chain for run 154787 (LHC11c), 70 k events reconstructed.

In addition to the extrapolation of the track from the central barrel to the EMCal interaction plane and the matching with a compatible nearby cluster, the electron trigger component must finally perform particle identification to issue a trigger decision. The selection of electron candidates is done using the E/pc information where the energy is measured from the EMCal cluster and the momentum from the central barrel track. The trigger component is initialized with default values for the cut of $0.8 < E/pc < 1.3$. The default cuts are stored in the HLT conditions database and can be overridden via command line arguments at configuration time (usually at start of run).

The performance of the electron trigger was studied using pp minimum bias data at 7 TeV with embedded J/Ψ events. Figure 6 shows the good agreement of the E/pc distributions obtained with the track extrapolation - cluster matching performed using the online algorithms compared to the ESD-based tracking (red).

To determine the possible improvement of the event selection for electrons with energies above 1 GeV, AliRoot simulations of the HLT chain using LHC11b10a pp minimum bias data at 2.76 GeV and the EMCal full geometry (10 super-modules) have been used. These studies have shown that at least a factor 5 to 10 in event selection can be gained compared to the single shower trigger, as shown in Figure 7.

5.3. *Jet trigger*

The EMCal online jet trigger component was developed to provide an unbiased jet sample by refining the hardware L1 trigger decisions. In fact, the HLT post-processing can produce a sharper turn on curve using the track matching capabilities of the online reconstruction chain. In addition, a more accurate definition of the jet area than the one provided by the hardware L1

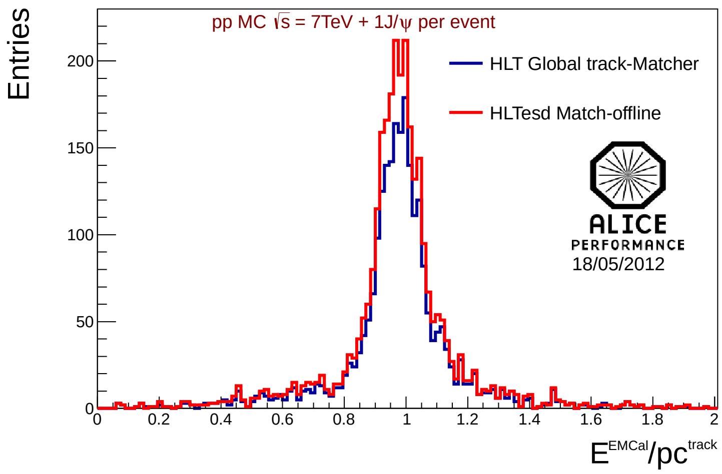

Figure 6. E/pc distributions obtained with the track extrapolation - cluster matching via the online algorithms compared to the ESD-based tracking (red).

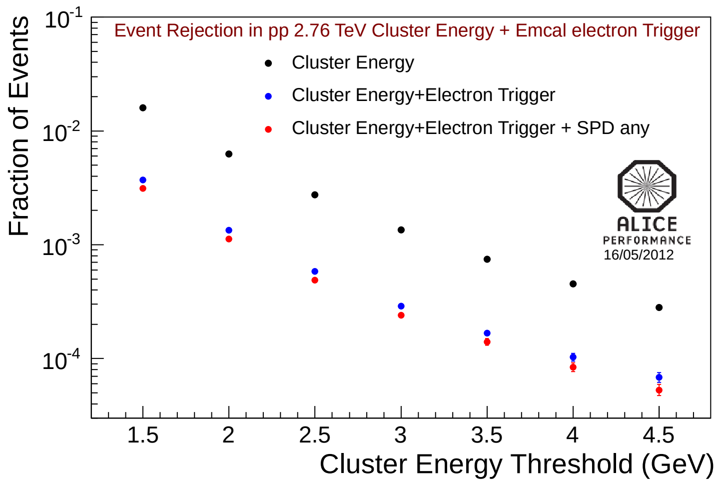

Figure 7. Improvement in the event selection for $E_{e^-} > 1$ GeV from AliRoot simulation (anchor to LHC11b10a) with minimum bias pp at $\sqrt{s} = 2.76$ TeV (EMCal full geometry). The red points are obtained with the requirement of one hit in one of the silicon pixel (SPD) layers to reject a higher fraction of photon conversions.

jet patch, can be obtained choosing a jet cone based on the jet direction calculated online. The combination of the hadronic and electromagnetic energy provides a measurement of the total energy of the jet by matching the tracks identified as part of the jet with the corresponding EMCal neutral energy.

The use of the HLT jet trigger also allows a better characterization of the trigger response as a function of the centrality dependent threshold by re-processing the information from the V0 detector directly in HLT.

Performance considerations, due to the high particle multiplicity in $PbPb$ collisions, impose that the track extrapolation is done only geometrically without taking into account multiple scattering effects introduced by the material budget in front of the EMCal. The pure geometrical extrapolation accounts for a speedup factor of 20 in the execution of the track matcher component with respect to the full-fledged track extrapolation used in pp collisions.

The identification of the jet tracks is performed using the anti-k_T jet finder provided by the FastJet package.

The EMCal jet trigger was only partially tested during the 2011 data taking period and will be fully commissioned for the LHC pPb run period in 2012.

6. Monitoring components

The role of the EMCal HLT reconstruction in *pp* collisions is targeted mainly on the monitoring functions since the expected event sizes are small enough for the complete collision event to be fully transferred to permanent storage.

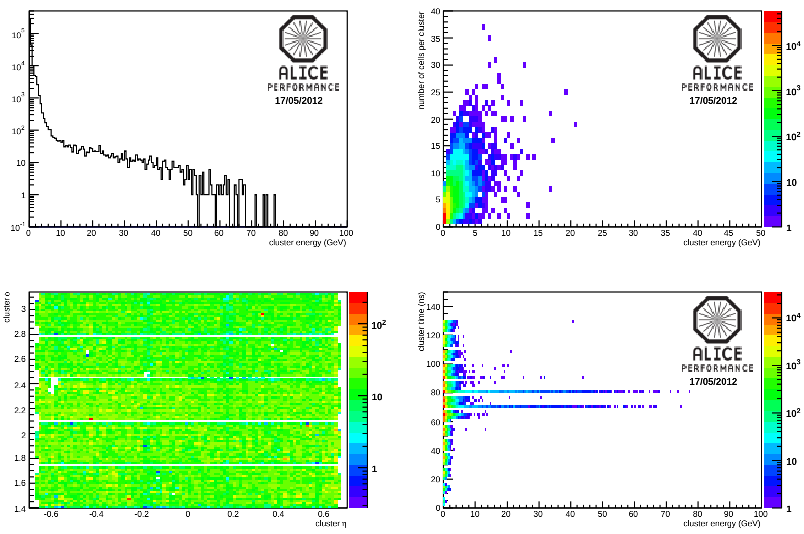

Figure 8. Output from the EMCal HLT monitoring component. Top left: cluster energy spectra as a function of the reconstructed cluster energy; bottom left: cluster position in η and ϕ coordinates; bottom right: cluster time distribution; top right: number of cells per cluster vs cluster energy. LHC11b period, $\sqrt{s}$ = 7 TeV *pp* data, 10 kEvent analyzed.

In this respect, two monitoring components have been developed and deployed in the online chain. The first component currently monitors reconstructed quantities, such as the cluster energy spectra and timing, the cluster position in the η and ϕ coordinates, and the number of cells per cluster as a function of the cluster reconstructed energy as shown in Figure 8.

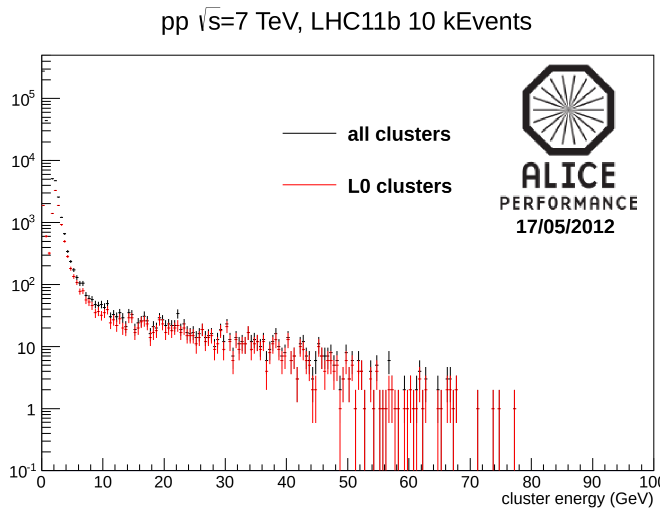

Figure 9. Energy spectrum for all clusters reconstructed by the EMCal (black points) superposed with the triggered cluster spectrum (i.e. clusters reconstructed which also carry the L0 hardware trigger bit set, red points).

The second component re-evaluates the EMCal hardware trigger decisions by recalculating the cluster energy spectrum for all the clusters with the L0 trigger bit set as shown in Figure 9. The L0 turn on curve can then be calculated online as the ratio between the triggered and the reconstructed cluster spectra and monitored for the specific run.

No recalculation of hardware L1 trigger primitives was possible during the 2011 data taking since the optical link from the EMCal L1 trigger unit could only installed during the 2011-2012

winter shutdown of the LHC hence the software development for the L1 trigger monitoring is still underway.

7. Conclusions

In *pp* collisions the bandwidth to mass storage is sufficiently large to allow the recording of the full data volume at the maximum event rate at which ALICE can be read out, so rejection of the accepted events at the HLT level is not needed. In this scenario the primary use of the EMCal HLT online chain relies on its monitoring capabilities as discussed in the present report.

On the other hand, in *PbPb* collisions, online post-filtering in the HLT is foreseen to provide an additional event rejection and to sharpen the jet trigger response at the threshold. A sharper trigger turn-on would be also relevant in *pp* running since it would lead to an optimization of the computing resources needed for the offline reconstruction. Finally, the EMCal HLT jet trigger is expected to reduce the bias with respect to the hardware jet patch algorithm. Studies are still underway to quantify the response of the EMCal HLT trigger chain for the different collision modes.

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